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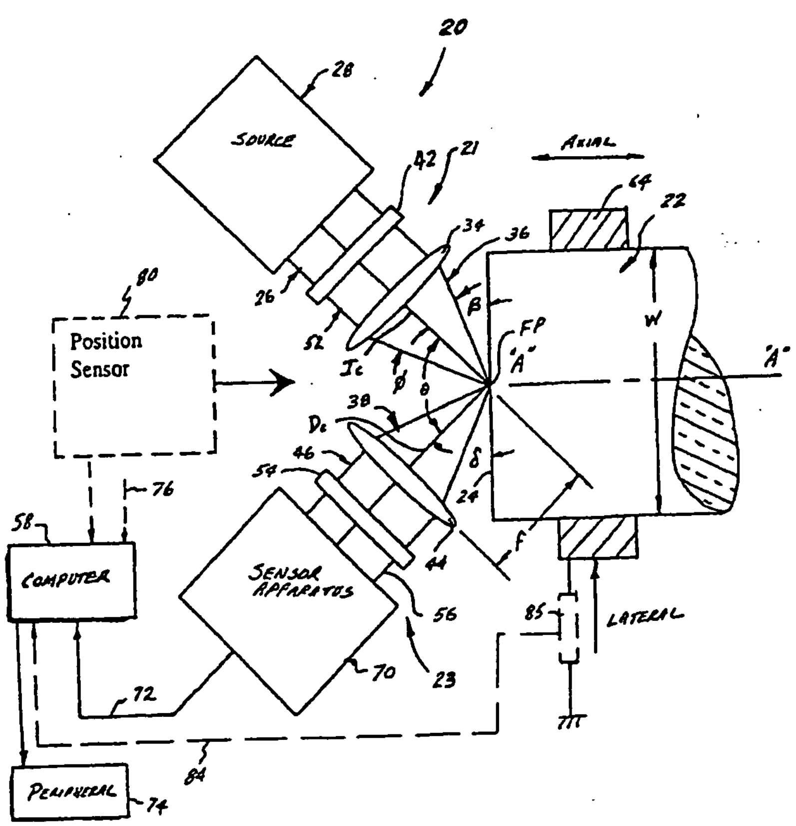

(57) Abstract: A method and apparatus for measuring an optical characteristic such as the index of refraction of an article. The method involves reflecting a converging beam from the surface at an angle to form a diverging beam having differing intensities at a plurality of segments (S_1-S_n) across its width. The intensity associated with the plurality of transverse segments are measured to generate intensity data, and the index of refraction (n) of the article is determined based upon the data. The angle between the converging and diverging beams is set to approximately Brewster's angle, and the light in the converging beam is parallel polarized. Refractive Index profiles may be generated by imparting movement between the article and the beam and taking readings at a plurality of points on the article.

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Method and Apparatus for Measuring Refractive Index

This application claims priority to and the benefit of Application Number 09/473,523, filed in the United States Patent and Trademark Office on December 28, 1999.

Field of the Invention

The present invention relates to a method and apparatus for measuring the refractive index in articles, such as optical fiber preforms, and in particular, to a method and apparatus which utilizes reflected light for such measurement.

Background of the Invention

A critical step in the production of optical fiber is verifying whether an optical fiber article (such as a preform or core cane) has a desired index of refraction. More particularly, an index of refraction profile, i.e., the index as a function of a dimension of the article (usually a radial width), is to be characterized. The reason for this screening and/or characterization is to ensure the end product manufactured from the article (e.g., an optical fiber) is of acceptable optical quality. For example, if the core cane were of inferior quality, the resulting fiber produced therefrom would likely be scrapped, wasting valuable manufacturing resources and capacity. Therefore, it is more desirable to discard inferior quality articles as early in the process as practicable by appropriate characterization thereof. The term "preform" as used herein means a consolidated article from which an optical fiber may be

drawn. It is also desirable to screen precursor articles used in optical fiber manufacture, such as core-cane or blanks.

One currently used method for measuring refractive index in glass articles such as core canes, involves scanning the cane from the side using a York apparatus (hereinafter the "York Method"). In the York Method, the cylindrical cane is exposed across its transverse extent (across its width) to a columnar light beam. As the beam is swept across and passes through the preform the light beam is refracted. The refracted light angle is then measured by a sensor positioned behind the article and transmitted to a computer. The computer interprets the refracted light angles to provide an index of refraction profile across the radial extent of the cane by way of a mathematical convolution.

Although the York Method is a valuable screening tool, it may provide erroneous results under certain circumstances. For example, diffraction problems from stria present in the preform may create erroneous readings, especially in large diameter core canes. Also, in the York process, a few bad data points may effect the entire profile because of the interdependence of the points. Furthermore, the York Method may yield erroneous refractive index values in regions of sudden change in the refractive index. Moreover, when using the York Method, elliptical or other non-round core cane shapes may adversely affect the profile generated.

Thus, there is a need for an accurate method and apparatus for measuring index of refraction in articles that minimizes or eliminates the afore-mentioned problems.

Summary of the Invention

In accordance with the invention, a method and apparatus are provided for accurately measuring an optical characteristic, such as in glass preforms, core canes or other transparent or translucent articles. According to a first aspect of the invention, a method for measuring index of refraction of an article is provided. The method involves directing a converging incident beam on the surface of an article at an angle to the surface, thereby forming a reflected

diverging beam. The diverging beam includes a plurality of transverse segments (e.g., S_1-S_n) across the beam width and, according to the method, the intensity associated with each is measured to generate intensity data. The index of refraction (n_{art}) of the article is then generated from the data by determining a minimum of the data. The method according to the invention is especially useful for measuring the refractive index in optical fiber articles such as core canes or preforms.

According to another aspect of the invention, the surface of the article is preferably located substantially coincident with the focal point of the converging beam and the surface of the article is substantially planar; manufactured, for example, by a precision grinding process. In a preferred embodiment, the method imparts relative motion between the article and the incident converging beam. The motion is preferably generated in a lateral direction, such that a refractive index profile across a width of the article may be derived. The profile is derived when the lateral motion, for example, moves the incident beam to a second point on the article. A second intensity measurement is taken at the second point (spaced from the first) to generate an index of refraction of at least one other point on the surface of the article. Most preferably, the article is moved in finite steps and intensity measurements are taken at each step. This enables generation of a refractive index profile as a function of a dimension of the article, for example, across a radial width of an optical fiber core cane or preform.

Preferably, the converging beam is formed by a beam producer, preferably including a laser source, by first passing a collimated beam through a polarizing filter, preferably a parallel polarizing filter, and then through a first optical focusing device, for example, a lens. According to the invention, it is preferable to set the angle between the converging beam center and diverging beam center to be approximately equal to an expected Brewster's angle θ_B of the article. An approximate Brewster's angle may be estimated based upon well known information tables or experience, for example.

Once the incident convergent beam is reflected off of the article's surface, the divergent beam passes into a beam receiver. The beam receiver receives

the diverging beam through a second optical device (e.g., a lens) included therein to produce another collimated beam. This reflected beam also preferably passes through a second parallel polarization filter. Within the beam receiver, the intensity of the plurality of segments (S_1-S_n) associated with the divergent beam are measured, for example, by an array of sensors (A_1-A_n). Upon taking the measurements, the actual Brewster's angle is derived from, and is correlated to, a minimum in the intensity data. Based upon the location of the minimum in the data and the approximate Brewster's angle initially used, a processor adds or subtracts from the approximate angle to find the actual Brewster's angle of the article's material. From this, the actual index of refraction (n_{art}) of the article at the point of measurement is determined according to the equation:

$$\theta_B = \tan^{-1} n_{art}/n_{med} \qquad \text{Equation 1}$$

where

θ_B is the actual Brewster's angle,

n_{art} is the refractive index of the material of the article 22, and

n_{med} is the refractive index of the medium the measurement is taken in, for example, air.

The principle under which the invention operates is as follows. Because the incident light beam is cone shaped, i.e., converging, each individual segment contained in the beam reflects off the surface at a different angle. Thus, the beam may be thought of as a plurality of segments oriented at a plurality of different angles of incidence to the surface. Because each segment is incident at a different angle, Fresnel's equations dictate a different reflected intensity is generated for each segment. It should be recognized that the minimum intensity segment corresponds to the actual Brewster's angle, i.e., where all the light that is polarized parallel to the surface is absorbed into the article and none is reflected; with larger intensity values being on either side of that angle. The number of segments is determined by the number of sensors included in the array, with a large number being preferred for better precision in finding the minimum; about 256 being most preferred. Once Brewster's angle

is determined, refractive index n_{art} is readily derived according to equation 1 listed above.

In accordance with another aspect of the invention, an apparatus is provided for determining an index of refraction of an article. The apparatus includes a beam producer that generates a parallel-polarized, converging incident beam which is reflected off a surface of the article to form a diverging beam, a beam receiver, including, for example, a sensor array, that measures the intensity data associated with a plurality of segments associated with the diverging beam, and a processor that receives the intensity data and determines an index of refraction therefrom.

The method and apparatus in accordance with the present invention results in a number of advantages over prior art methods and apparatus. For example, the precision of determining the index of refraction (n_{art}) is improved. Also, the measurement of refractive index profile is not affected by large changes in profile slope. Furthermore, stria affect the results to a lesser extent that the prior art York method. Other aspects, features and advantages of the invention will be understood with reference to the following detailed description, claims and appended drawings.

It is to be understood that both the foregoing general description and the following detailed description are merely exemplary of the in invention, and are intended to provide an overview or framework to understand the nature or character of the invention, as claimed. The accompanying drawings are included to provide a further understanding of the invention, and are incorporated into and constitute a part of the specification. The drawings illustrate one or more embodiments of the invention, and together with the description serve to explain the structure, principle and operation of the invention.

Brief Description of the Figures

Fig. 1 is a plan view of the apparatus in accordance with the invention.

Fig. 2 is a detailed partial plan view illustrating the beam segments.

Fig. 3 is a graphical plot illustrating the intensity of the various beam segments at a single point.

Fig. 4 is a perspective view of the article to be measured illustrating the points across the profile where measurements are taken.

Fig. 5 is a graphical plot illustrating of a refractive index profile of an article taken in accordance with the invention.

Detailed Description of the Invention

Reference will now be made, in detail, to the present preferred embodiment of the invention with reference to the attached drawings. Wherever possible, the same reference numerals shall be use throughout to refer to the same or like parts.

In accordance with the invention, as best shown in Fig. 1, an apparatus 20 is illustrated for measuring the refractive index of an article 22, such as a consolidated optical fiber preform, optical fiber core cane, or other transparent or translucent article. The refractive index may be measured at a single point or at multiple points. Thus, the invention is useful for providing an accurate index of refraction of article if the material includes a single refractive index or, alternatively, a refractive index profile. An article exhibits a profile when, for example, the article includes material exhibiting different refractive indices at various points therein. The invention has particular utility for providing a refractive index profile across a radial width of, for example, an optical fiber preform or core cane.

According to the invention, a method of determining an index of refraction (n_{art}) of an article 22 is provided. The method comprises the following steps. First, an appropriate surface 24 of the article 22 is exposed to a preferably conical shaped, convergent incident beam 36. By way of example, the article 22 shown is an optical fiber core cane. A core cane is a long slender rod that includes a core portion of doped silicon oxide and a near

clad portion of preferably pure silicon oxide. The core cane is later overclad with high purity glass soot and further consolidated to form the final preform from which optical fiber is drawn.

To prepare the article 22 for measurement, the surface 24 of the article where the refractive index measurement is to be taken is precision ground such that the surface is substantially planar. The surface 24 is also oriented relative to the apparatus 20 such that an angle β between the incident beam center Ic and the surface 24 and the angle δ between the divergent beam center Dc and the surface 24 are approximately equal. In the case where the article 22 is a core cane, the end surface 24 is precision ground perpendicular to the axial axis A-A of the cane 22. Preferably, the surface finish of the ground surface 24 is ground to a very fine polish.

The article 22 is then preferably mounted in a moveable fixture 64 such that the relative position of the article relative to the converging incident beam 36 may be adjusted. The reasons for desiring position adjustment are two-fold. First, it is desired to have the focal point FP of the converging beam 36 focused such that the focal point FP is substantially coincident with the surface 24, i.e., focused at the surface. By the term substantially focused, it is meant that the beam 36 be focused to within about 100 microns from the surface 24. Therefore, some adjustment in the axial direction may be desirable and achieved by any suitable means such as a mechanical stop or a motor which positions the article 22. Second, adjustment allows the position of the article 22 to be moved relative to the apparatus 20 in, for example, a direction opposed to the axial axis, such as a lateral direction. In this way, a refractive index profile across the radial width W of the article 22 may be generated. Thus, for example, a profile measurement may be made across the end of an article as shown in Fig. 4.

The converging incident beam 36 is formed by a beam producer 21 including a source 28, a polarizing filter 42 and a optical focus device 34, each of which will be described in more detail herein. The source 28 generates a collimated beam 26 having a preferable width of about 1cm, although other dimensions will work as well. The source 28 is preferably a semiconductor

laser or other source capable of forming a high intensity collimated light beam. The source 28 preferably emits a clean beam that is preferably approximately parallel polarized with respect to the surface of the article. Light from the source 28 preferably exhibits wavelengths of between about 400 nm to about 3000 nm, with 1550 nm being most preferred. Next, the collimated beam 26 is passed through a parallel polarization filter 42 to form a collimated parallel polarized beam 52. The filter 42 only allows parallel polarized light to pass through. A parallel polarized, converging beam 36 is next formed by passing the polarized beam 52 through the first optical focusing device 34, such as an optical lens having a focal ratio of about 1.0. Focal ratios of 1.0 or greater would likely work also, but at the expense of requiring more precision in the setting of the initial guess of Brewster's angle. Preferably, the focal ratio is as small as possible. Notably, a focal ratio of 1.0 provides an angle ϕ in the converging beam 36 with a spread of about 1.092 radians. This corresponds to a range of refractive index (n_{art}) measurement of about +/- 0.813 if the article has a refractive index close to that of glass (about 1.5).

It is important to recognize that the angle ϕ provides the spread within the beam 36 needed to produce a plurality of intensity values within the reflected diverging beam 38. By way of example, as shown in Fig. 2, the incident beam center Ic reflects from the surface 24 at a first angle incident to the surface and reflects to form the divergent beam center Dc. A different portion of the beam, for example the beam edge labeled Ie, reflects at a different incident angle to the surface 24 and reflects to form the divergent beam edge De. Because the central beam and the edge beams are oriented at different angles of incidence to the surface 24, different amounts of light are absorbed / reflected for each beam portion as described by Fresnel's equations. Thus it should be recognized that present in the spread of the converging beam 36 there are nearly an infinite number of beam portions throughout the arcuate extent thereof. Each portion exhibits a different angle of incidence to the surface 24. Thus, there are also nearly an infinite number of reflected beam portions throughout the arcuate extent of the diverging beam 38. Therefore, it should also be recognized that there are an infinite number of

angles of incidence to the surface 24 within the spread of the converging beam 36. By measuring the reflected portions (in practicality, they are measured in groups referred to herein as "segments"), and determining the minimum thereof, an index of refraction may be determined as is described fully later herein.

As discussed before, the surface 24 of the article 22 is preferably positioned such that it is located substantially coincident with the focal point FP of the converging incident beam 36. A slight out of focus condition may be present and still fall within the definition of being "substantially coincident." By way of example and not by limitation an out of focus condition of about 3% of the focal length is tolerable. For example, it may be desirable to have a slight out of focus condition to get a more "averaged" refractive index. By getting the result from a larger area, the error in the measurement may possibly be reduced. The converging beam 36 is reflected from the surface 24 at a predetermined/preset angle θ measured between the respective beams centers Ic, Dc. The angle θ is manually set by an operator or permanently fixed to an approximate Brewster's angle for the material to be tested. If only one material is to be measured where the index will always be within a specific range, for example, with an optical preform, then the approximate Brewster's angle may be permanently fixed by rigidly connecting the beam producer 21 and beam receiver 23 together. Operator adjustment of the approximate Brewster's angle θ may only be required if the apparatus 20 is to be used to test refractive indexes for a wide variety of materials.

Brewster's angle θ_B is the angle at which all of the incident light that is parallel polarized to the surface 24 is absorbed into the article 22 and virtually none is reflected. Each transparent or translucent material exhibits an inherent Brewster's angle, i.e., it is a material property. Approximates of Brewster's angles for any material may be derived from many published sources or from experience with the materials to be tested. One source is a paper by David C. Boyd and David A. Thompson entitled "Glass," Kirk-Othmer: Encyclopedia of Chemical Technology, Vol. 11, Third Edition, pages 830-831 which lists refractive indexes for various transparent materials. It should be understood

that the angle θ does not have to be set exactly, and that quite a wide range of error is allowed in setting the angle due to the converging nature of the diverging beam 36. As long as the setting of the angle θ falls within the beam range ϕ, the index measurement method and apparatus according to the invention will operate as intended.

According to the invention, the intensity associated with each of the plurality of segments S_1-S_n in the diverging beam 38 are measured to generate intensity data. Preferably, what is measured is the intensity of the segments of the collimated beam 56 that correspond directly to the segments in the diverging beam 38. For example, segment S_1 corresponds to segment S_1' and so on. The diverging beam 38 is preferably refocused into a collimated beam 46 by second optical focus device 44, such as another lens. The optical focus device 44 may be the same size or different that focusing device 34. Next, the collimated beam 46 is again appropriately parallel polarized by filter 54 to be sure that only the parallel polarized components of the beam 56 are measured. Is it possible to eliminate elements focus device 44 and filter 54 and measure the diverging beam directly with an array of sensors. However, filter 54 reduces noise and the focus device 44 aids in simplifying the computational analysis. Thus it is more desirable from a practical standpoint to include them. The intensity data for the of the various segments of the collimated beam 56 are measured by a sensing apparatus 70, which includes, for example, an array of sensors 69 including sensors A_1-A_n. By way of example, there may be between 2 and millions of sensors in the array, with about 256 sensors being preferred. A single intensity (power) value is generated for each segment and the number of segments is defined by the number of sensors in the array 69.

The sensor data is then sent from each sensor A_1-A_n through a transport mechanism 72, such as a cable, to a computer or processor 58. The processor 58 determines the minimum of the data and which corresponding individual sensor in the sensor apparatus 70 is receiving the minimum signal. Any appropriate computer algorithm may be utilized to determine the minimum. For example, each sensor value may be tested in a swept fashion from A_1-A_n, compared to the previous sample and the minimum detected therefrom. From

this information, i.e., the sensor location where the minimum occurs, the actual Brewsters angle θ_B is derived as is described below. Once the actual Brewsters angle θ_B is derived, the index of refraction n of the article 22 is determined from the data and may be displayed or printed out by an applicable peripheral 74 such as a monitor, display or printer.

According to the invention, the index n_{art} is derived as follows. First, the apparatus 20 is set to the appropriate orientation with respect to the article 22, depending upon the material of the article 22 and focal length of the lens 34. This involves setting the approximate Brewster's angle θ for the apparatus 20 and focusing the converging beam 36 onto the surface 24. For a high purity glass material, such as fused silica, the index of refraction n is approximately 1.459. If the test is taken in air which has an index of refraction of n_{med}=1.000, then the approximate Brewster's angle θ is set equal to 55.573 degrees as calculated in accordance with Equation 1 above.

Second, the angles β and δ are set to be approximately equal to one another. This is generally accomplished by a fixture 64 (Fig. 1, 4) which is positioned in a preset mechanical orientation to the beam producer 21 and the beam receiver 23. This may be accomplished by mounting the beam producer 21, the beam receiver 23 and the fixture 64 to a common rigid base (not shown). An adjustment mechanism (not shown) may be employed which adjusts the angle θ in fine increments by moving the beam producer 21 and the beam receiver 23 in equal amounts relative to the base. A high precision angle sensor (not shown) may also be employed to provide fine angular data to the processor 58 in line 76 regarding the angle θ.

Third, the relative position between the article 22 and the converging beam 36 may be adjusted such that the focal point FP is approximately positioned at the surface 24. This may be accomplished, as shown in Fig. 4, by having the fixture 64 with a preset stop 78 to precisely position the surface 24 axially relative to the apparatus 20 (not shown for clarity). Optionally, the axial position may be determined by a position sensor 80 (Fig. 1) where the position of the article 22 is moved via an axially moveable fixture 64 to coincide with a preset position stored in memory in the processor 58. A feedback loop

may be provided in the processor 58 which controls a motor (not shown) to adjust the axial position of the fixture, and thus the article 22.

As is illustrated in Fig. 3, data generated from the array 69 of Fig. 2 is plotted. The plot includes normalized segment intensity on the y axis and segment number on the x axis. The intensity data plotted as line 65 shows differing intensities for each segment and includes a minimum at 67, the position of which corresponds to the actual Brewster's angle θ_B. If the approximate Brewster's angle θ, by chance, is set exactly equal to the actual Brewster's angle θ_B, i.e., the operator's guess was exactly right, then the minimum is designed to occur at the center of the array (at position 67 between A_5 and A_6). If the minimum 68 is offset from the center as illustrated by dotted line 66, the minimum 68 being located between sensors A_7 and A_8, then the actual Brewster's angle θ_B is calculated according to equation 2. This occurs when the operator's guess of approximate Brewster's angle θ was slightly off.

$$\theta_B = \theta - \tan^{-1}(x / f) \qquad \text{Equation 2}$$

where

x is the distance away from the center of the array 69' (Fig. 2), and

f is the focal length of the lens 44 (Fig. 1). In short, any suitable method may be used to correlate the position of the minimum sensed by the array 69 to the starting position such that the Brewster's angle may be derived.

According to the invention, a refractive index profile may also be obtained. This is accomplished by adding the additional step of imparting relative motion between the article 22 and the incident converging beam 36 and then taking one or more additional measurements at various points on the article. For example, as shown in Fig. 4, the article 22 may be moved, say from 5 to 6, a finite distance d and a second intensity measurement may be taken. At this position, the processor 58 again executes the minimization algorithm and determines Brewster's angle θ_B for that second point. From that, the index of refraction at the second point is derived according to Equation 1. More preferably yet, lateral relative motion is imparted between the converging beam 36 and the article 22 by moving the article 22 in finite lateral steps and taking intensity measurements at each step. Preferably, readings are taken at

a plurality of points across the lateral extent (width) of the article. The finer the increments, the better the profile that is developed. The force F to impart lateral motion may be provided by any suitable motor, such as a stepper motor and a suitable ball-screw mechanism, for example.

At each step, the index of refraction is measured and recorded in memory. Also stored in memory is the position data transmitted in line 84 that is generated from a lateral position sensor 85 (Fig. 1). Thus, as best shown in Fig. 3 and Fig. 4, stored in memory are lateral positions for a plurality of points (e.g., 1-10) and index of refraction values at the various points across the width of the article 22. From this data, an index of refraction profile that is a function of a dimension of the article 22 may be generated. The index profile may be plotted or displayed on the peripheral 74. It should be recognized that a profile may be generated for the entire surface 24 or for only a portion of the surface.

A typical profile for a core cane measured in accordance with the invention is shown in Fig. 5. The plot includes refractive index plotted on the y axis and radial position number across the width of the cane plotted on the x axis. Alternately, an actual dimension value may be plotted on the x axis. As is illustrated by the solid curve labeled 86, when a small number of finite increments are used (e.g., about 10), the refractive index profile is somewhat rough. As more points across the article 22 are used as illustrated by dotted line 88, the resolution of the plot becomes much better. By way of example, it is desired to take approximately 1 readings for every 10 μm across the article for providing a well defined plot.

It will be apparent to those of ordinary skill in the art that various modifications and variations can be made to the present invention without departing from the scope of the invention. Thus, it is intended that the present invention cover the modifications and variations provided they come within the scope of the appended claims and their equivalents.

Claims

What is claimed is:

1. A method of determining a refractive index of an article (22), comprising the steps of:
   (a) reflecting a converging incident beam (36) at an angle to a surface (24) of the article (22) to form a diverging beam (38) having differing intensities at a plurality of segments (S_1-S_n) across a width of the diverging beam (38),
   (b) measuring reflected intensity associated with the plurality of segments (S_1-S_n) to generate intensity data, and
   (c) determining a refractive index (n) of the article from the intensity data.

2. The method of claim 1 wherein the surface (24) is located substantially coincident with a focal point (FP) of the converging incident beam (36).

3. The method of claim 1 wherein the surface (24) is substantially planar.

4. The method of claim 1 wherein the article (22) comprises an optical fiber preform or core cane.

5. The method of claim 4 comprising an additional step of measuring the index of refraction (n) at multiple points on the surface (24) of the preform or core cane to obtain a refractive index profile that is a function of a dimension of the preform or core cane.

6. The method of claim 1 comprising an additional step of imparting relative motion between the article (22) and the incident converging beam (36) and taking a second intensity measurement to determine an index of refraction (n) of at least one other point on the article (22)

7. The method of claim 6 wherein the step of imparting relative motion comprises moving the article (22) in finite steps and taking intensity measurements at each step.

8. The method of claim 6 comprising an additional step of measuring the index of refraction (n) at multiple points on the surface (24) of the article (22) to obtain a refractive index profile that is a function of a dimension of the article.

9. The method of claim 1 comprising an additional step of forming the incident converging beam by passing a collimated beam (26) through a first optical focusing device (34).

10. The method of claim 9 comprising an additional step of passing the converging beam through a parallel polarizing filter (42).

11. The method of claim 1 wherein the converging beam is parallel polarized.

12. The method of claim 1 comprising an additional step of setting an angle (θ) between the converging beam and diverging beam approximately equal to an expected Brewster's angle (θ_B) of the article (22).

13. The method of claim 1 comprising an additional step of passing the diverging beam (38) through a second optical device (44) to produce a collimated beam (46).

14. The method of claim 1 wherein the step of measuring the intensity of the plurality of segments (S_1-S_n) is accomplished by an array of sensors (69).

15. The method of claim 1 wherein the step of determining the index of refraction (n) includes a further step of determining the actual Brewster's angle based upon a minimum of the intensity data.

16. A method of determining a refractive index of an article (22), comprising the steps of:

(a) reflecting a parallel-polarized, converging incident beam (36) off of a surface (24) of the article (22) at an angle approximating Brewster's angle to form a divergent beam (38) having differing intensities at a plurality of segments (S_1-S_n) thereof,

(b) measuring the intensity associated with the plurality of segments (S_1-S_n) to generate intensity data, and

(c) determining an index of refraction (n) of the article based upon the intensity data.

17. A method of determining a refractive index profile of an article (22), comprising the steps of:

(a) reflecting a parallel-polarized, converging incident beam (36) from the surface (24) of the article (22) at an angle approximating Brewster's angle to form a diverging beam (38) having differing intensities at a plurality of segments (S_1-S_n) across a width thereof,

(b) measuring the intensity associated with the plurality of segments (S_1-S_n) to generate intensity data,

(c) determining an index of refraction (n) based upon the intensity data, and

(d) moving a position of the article relative to the converging incident beam (36), and

(e) repeating steps a-d a plurality of times wherein an index of refraction profile across at least a portion of the surface (24) is generated.

18. An apparatus for determining an index of refraction of an article (22), comprising:

(a) a beam producer (21) that generates a parallel-polarized, converging incident beam (36), the producer (21) adapted to be oriented relative to a surface (24) of the article (22) at

approximately Brewster's angle such that the converging incident beam (36) reflects off the article (22) to form a diverging beam (38) having a plurality of differing intensity segments (S_1-S_n),

(b) a beam receiver, including a sensor array, that measures an intensity associated with the plurality of transverse segments (S_1-S_n) and generates intensity data, and

(c) a processor which receives the intensity data and determines an index of refraction (n).

19. A method of determining an optical characteristic of an article (22), comprising the steps of:

reflecting a converging incident beam (36) at an angle to a surface (24) of the article (22) to form a diverging beam (38) having differing intensities at a plurality of segments (S_1-S_n) across a width of the diverging beam (38),

measuring reflected intensity associated with the plurality of segments (S_1-S_n) to generate intensity data, and

determining an optical characteristic of the article from the intensity data.

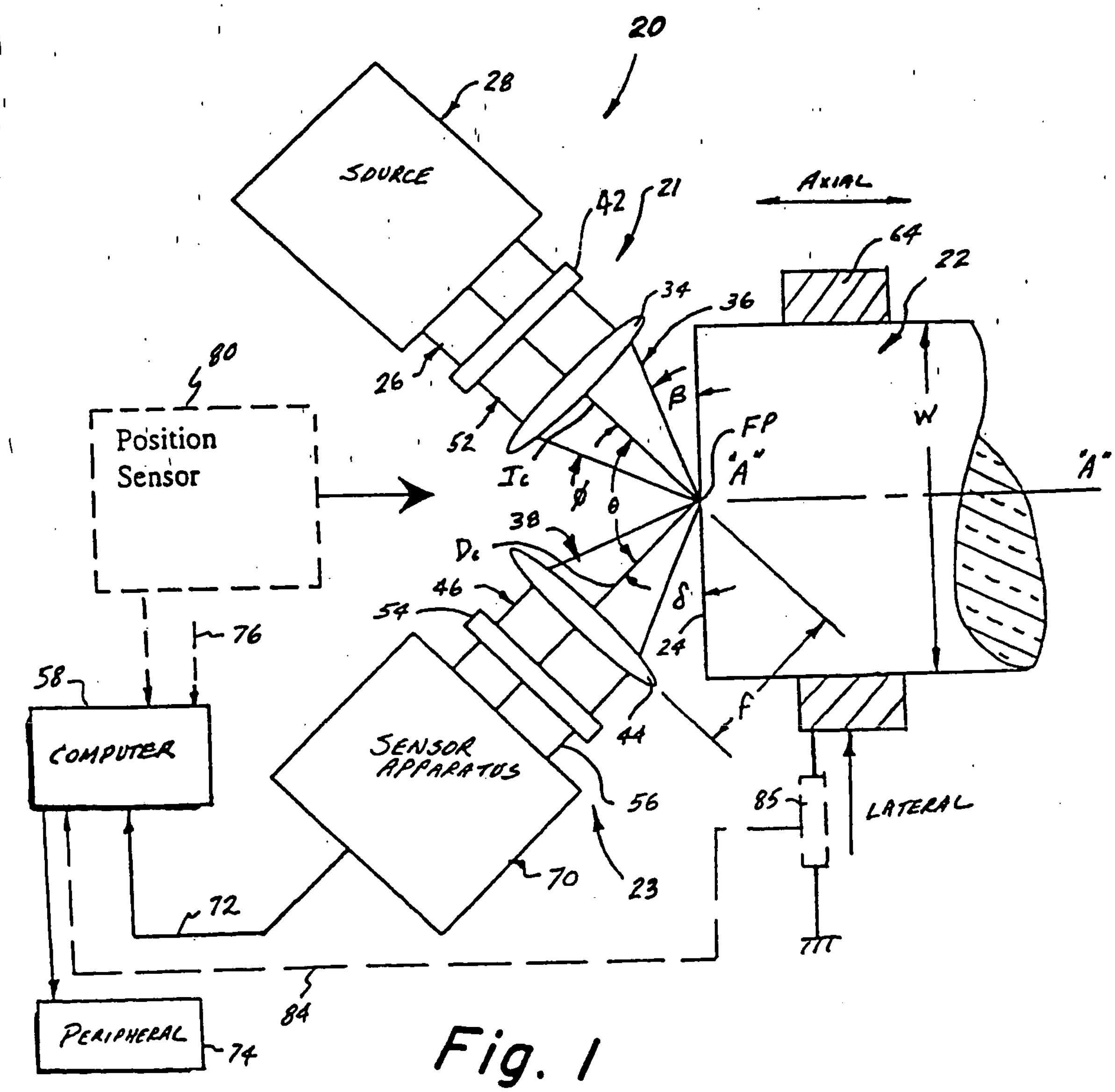
20
28
SOURCE
42
21
AXIAL
64
22
34
36
26
80
Position Sensor
52
β
W
FP
"A"
"A"
I_c
ϕ
θ
38
D_c
46
δ
54
24
76
58
COMPUTER
F
44
SENSOR APPARATUS
56
85
LATERAL
70
23
72
84
PERIPHERAL
74

Fig. 1

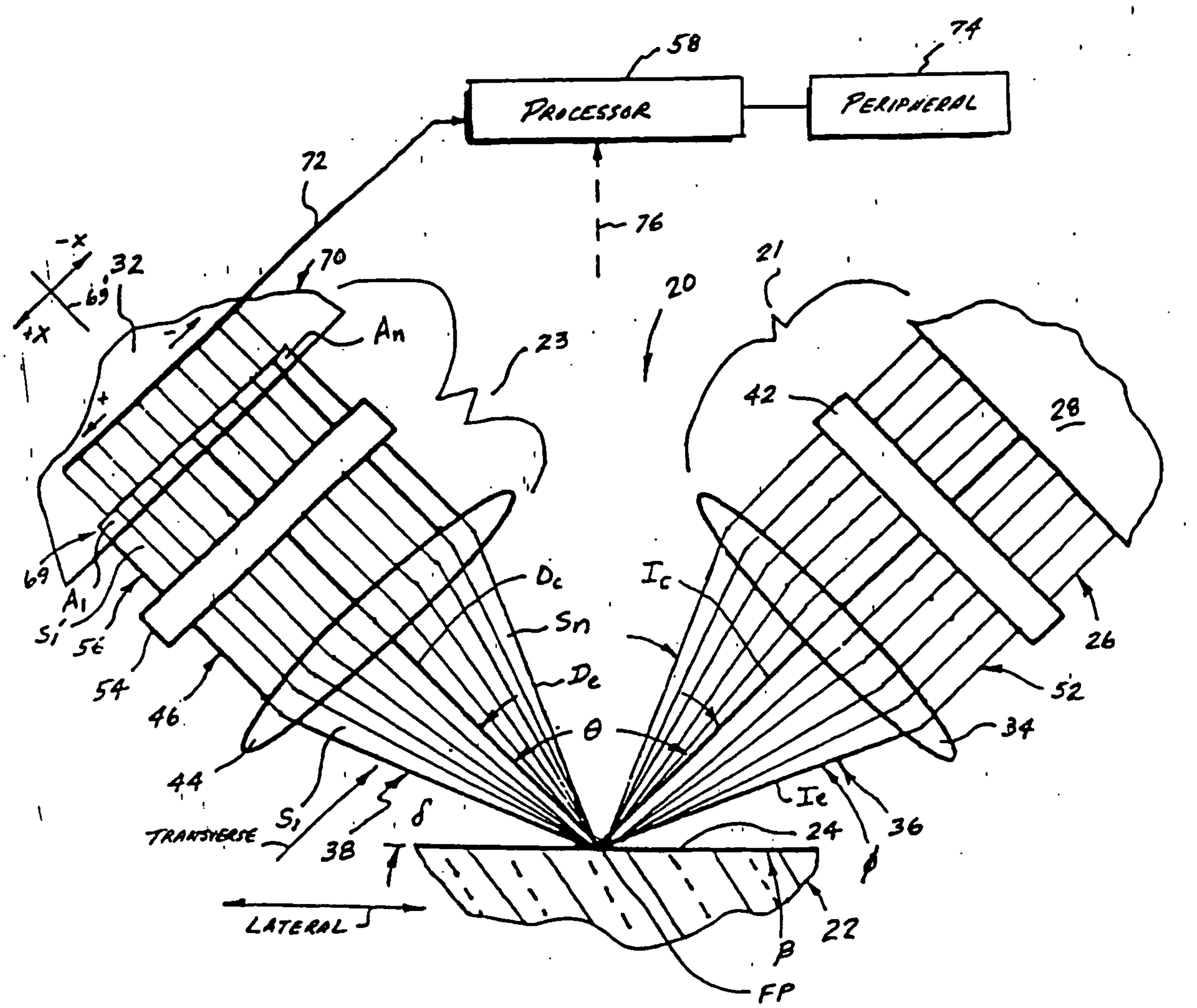
PROCESSOR
PERIPHERAL
58
74
72
76
20
21
23
32
70
An
28
42
-X
+X
69
Dc
Ic
Sn
De
θ
A1
S1
56
54
46
44
26
52
34
36
Ie
24
TRANSVERSE
38
δ
LATERAL
22
β
FP

Fig. 2

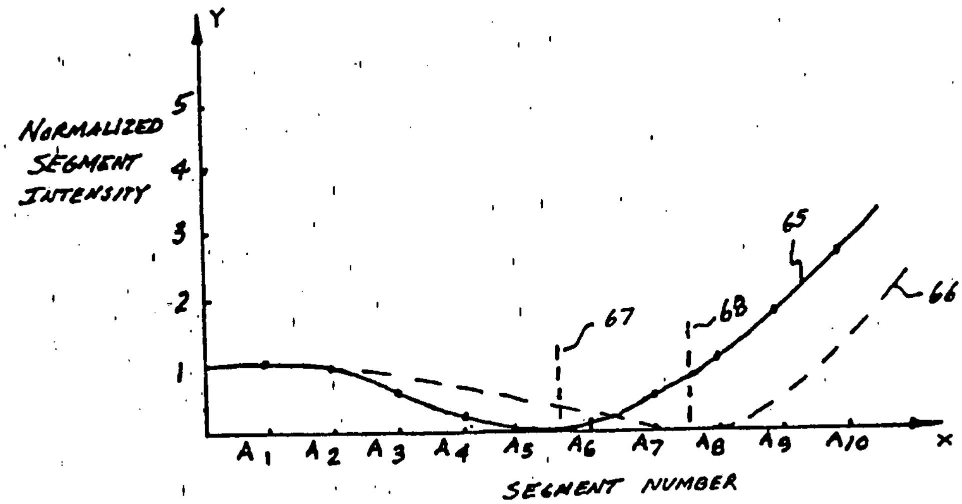
Y
NORMALIZED SEGMENT INTENSITY
5
4
3
2
1
65
66
67
68
A1 A2 A3 A4 A5 A6 A7 A8 A9 A10
X
SEGMENT NUMBER

Fig. 3

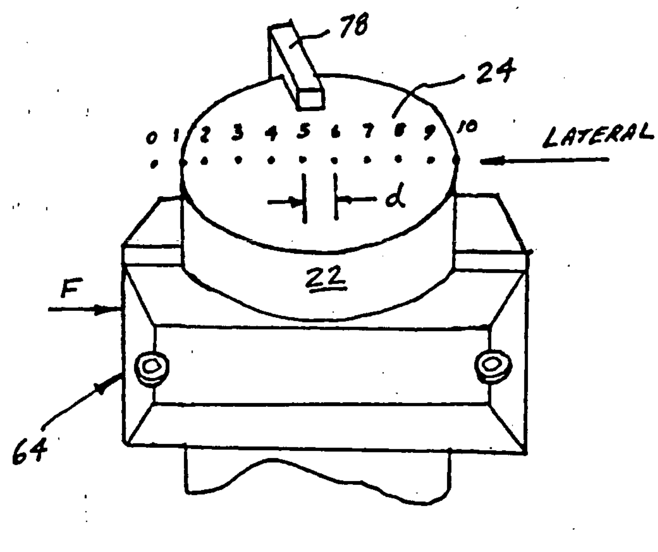
78
24
0 1 2 3 4 5 6 7 8 9 10
LATERAL
d
22
F
64

Fig. 4

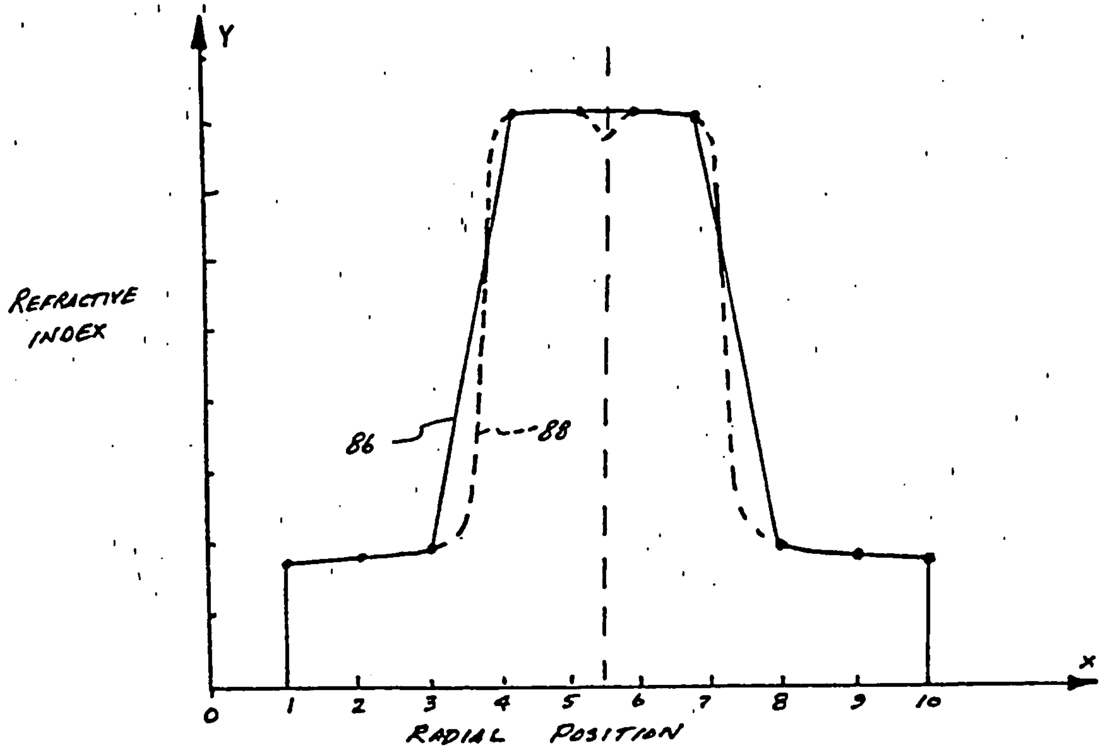

Fig. 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/33693

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01N21/41

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 4 672 196 A (CANINO LAWRENCE S) 9 June 1987 (1987-06-09) figures 7,9,11 column 1, line 15-17 column 14, line 58 -column 18, line 55	1-11,14, 19 16-18
A	US 4 227 806 A (WATKINS LAURENCE S) 14 October 1980 (1980-10-14) abstract	1,2,4-9, 16-18
A	US 5 125 740 A (SATO HIDEMI ET AL) 30 June 1992 (1992-06-30) column 5, line 11 - line 22; figure 3A	1,16-19

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 May 2001	06/06/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Scheu, M

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INTERNATIONAL SEARCH REPORT

In. .nation on patent family members

Internati l Application No
PCT/US 00/33693

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
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			JP	60242308 A	02-12-1985
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US 5125740	A	30-06-1992	JP	2244106 A	28-09-1990